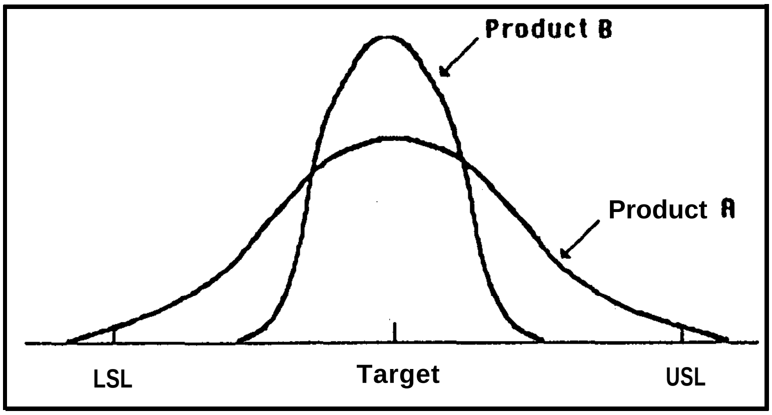
figure 1.4




Two measurements used to quantify variability with regard to lower spec limits (IAL), target and upper spec limits (USL) are $C_p$ and $C_{pk}$. The $C_p$ index was designed to compare variability with only LSL and USL; the formula is

$$C_p = \frac{(USL - LSL)}{6\hat{\sigma}} \quad \text{where} \quad \hat{\sigma} = \sqrt{\frac{\sum y_i^2 - n\bar{y}^2}{n-1}}\ ; \quad \bar{y} = \frac{\sum y_i}{n}$$

According to accepted standards in industry, $C_p$ values less than 1.00 are unacceptable, values between 1.0 and 1.3 are marginally satisfactory and values greater than 1.3 are desired. Since the $C_p$ value dots not take the target value into consideration, a new measurement $C_pk$ was developed. To calculate, use the lesser 'f $\left(\frac{USL - \bar{y}}{3\hat{\sigma}}\right)$ or $\left(\frac{\bar{y} - LSL}{3\hat{\sigma}}\right)$. Interpretation of Cp values is the same as that of $C_{pk}$ values. See table 1.3 for an approximate relationship between $C_{pk}$ and number of defects.

table 1.3

| $C_{pk}$ | Number of defects |
|---|---|
| .50 | 133,600 PPM |
| .67 | 71,800 PPM |
| .80 | 16,400 PPM |
| .90 | 6,900 PPM |
| 1.00 | 2700 PPM |
| 1.33 | 66 PPM |
| 1.67 | <1 PPM |
| 2.00 | <1 PPM |
| 3.00 | <1 PPM |
| 4.00 | <1 PPB |

This information was obtained from an R&M 2000 Variability Reduction Program slide prepared by HQ USAF/LE-RD

## 1.6 Objective of Experimental Design

When testing the effects of input factors on the output, it is desired to be able to ascertain causality, not just correlational relationships. Just as pointed out in section 1.4, a 'high correlation does not necessarily relate to the cause of the problem. To ascertain the causality of an input factor it is important to ensure that changes in the output occurred because of changes in the input and not some other related factor. To accomplish this task, experiments must be designed such that input factors are uncorrelated and all *nuisance variables* (variables not controlled) have their effects averaged out over all experimental conditions. This procedure is referred 10 as ***randomization*** and consists of running experimental conditions in a random sequence. The advantage of randomization is that it averages out the effects of all nuisance variables. This is especially important when the brainstorming process fails to identify factors and/or some factors cannot be measured or controlled in the experiment.

As an example demonstrating the need for randomization, consider the following: A new product is being tested using two different bonding agents.